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(Revision of
IEEE Std 259-1994)

IEEE Standard Test Procedure for Evaluation of Systems of Insulation for Dry-Type Specialty and General-Purpose Transformers

Sponsor

**Transformers Committee
of the
IEEE Power Engineering Society**

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IEEE-SA Standards Board

Abstract: A uniform method by which the thermal endurance of electrical insulation systems for dry-type specialty and general-purpose transformers can be compared is established. Covered are insulation systems intended for use in the types of transformers described in NEMA ST 1-1988 and NEMA ST 20-1992.
Keywords: aging, evaluation, dry-type, insulation system, thermal, transformers

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Introduction

(This introduction is not part of IEEE Std 259-1999, IEEE Standard Test Procedure for Evaluation of Systems of Insulation for Dry-Type Specialty and General-Purpose Transformers.)

This standard was developed to provide a test procedure for evaluating the thermal endurance of insulation systems for dry-type specialty and general-purpose transformers covered by NEMA ST 1-1988 and by NEMA ST 20-1992. Generally these dry-type transformers are used with the primary windings connected to secondary distribution circuits of 600 V nominal and below to supply electric power to lighting systems, heating systems, signaling systems, machine tool controls, industrial controls, and other power loads in commercial, institutional, and industrial applications.

The IEEE charged its technical committees with the responsibility for developing test procedures for the thermal evaluation and classification of insulation systems used in electrical equipment. These are to be in general accord with IEEE Std 1-1986. The principal objective is to enable the performance of new and old insulation systems to be compared directly in a practical way and in a reasonable time, and to provide a sound basis for introducing new insulation systems into service.

Experience has shown that the thermal life characteristics of composite insulation systems cannot be reliably inferred solely from information concerning component materials. To assure satisfactory service life, insulation specifications need to be supported by service experience or life tests. Accelerated life tests are being used increasingly to evaluate the many new synthetic insulating materials that are available, thus shortening the period of service experience required before they can be used with confidence. Tests on complete insulation systems, representative of each type of equipment, are necessary to confirm the performance of materials for their specific functions in the equipment.

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IEEE Standard Test Procedure for Evaluation of Systems of Insulation for Dry-Type Specialty and General-Purpose Transformers

1. Overview

This standard provides guidelines for preparing samples, conducting test, and analyzing results of test procedures performed to evaluate insulation systems designed for dry-type specialty and general-purpose transformers. The information in this standard is presented in three principal sections:

a) *Test specimens.* Describes the types of test specimens that are suitable for use in insulation system thermal evaluations.

b) *Test procedures.* Recommends a basic test cycle that is suitable for thermally evaluating insulation systems. The test cycle consists of a series of exposures to heat, vibration, thermal shock, moisture, and voltage representing the cumulative effects of long service under accelerated conditions. Information is included for selecting test conditions based on transformer application.

c) *Interpretation of data.* Provides guidelines for establishing the criteria of failure and methods for analyzing and interpreting test results.

Some transformers may have special requirements other than those included in this standard. In these cases, special exposures or tests should be added to the test cycle. It is all-important that when candidate and reference insulation systems are compared, test specimens of both systems shall be subjected to precisely the same test cycle.

1.1 Scope

The intent of this standard is to establish a uniform method by which the thermal endurance of electrical insulation systems for dry-type specialty and general-purpose transformers can be compared. These insulation systems are intended for use in the types of transformers described in NEMA ST 1-1988[1] and NEMA ST 20-1992. In general, these dry-type transformers are used with the primary windings connected to secondary distribution circuits of 600 V nominal and below.

[1]Information on references can be found in Clause 2.

Thermal degradation generally is one of the principal factors affecting the function of most insulating materials. It is the principal environmental factor in this standard. Other environmental factors such as vibration, thermal shock, and moisture are included to simulate operating conditions. These factors have been chosen in such a way as to develop and promptly disclose any significant weakness during the temperature aging of an insulation system.

This standard provides a statistical method for establishing a life-temperature relationship for an insulation system. This life-temperature relationship is relative. To have any significance, it must be supported by adequate field service data or it must be compared to similar life test data for insulation systems with known field-service reliability.

2. References

This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

ASTM E104-85(1991), Standard Practice for Maintaining Constant Relative Humidity by Means of Aqueous Solutions.[2]

IEEE Std 1-1986 (Reaff 1992), IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.[3]

IEEE Std 99-1980 (Reaff 1992), IEEE Recommended Practice for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment.

IEEE Std 101-1987 (Reaff 1995), IEEE Guide for the Statistical Analysis of Thermal Life Test Data.

NEMA ST 1-1988, Specialty Transformers (Except General-Purpose Type).[4]

NEMA ST 20-1992 (Reaff1997), Dry-Type Transformers for General Applications.

3. Insulation test specimens

Whenever possible, actual transformers should be used for the thermal evaluation of insulation systems. In the case of small transformers, they are the simplest, most direct, and least expensive test specimens. Some guidelines that can be used in selecting these specimens are given in 5.4.

In those cases where the actual transformer is too large to use as a test specimen, a representative-size specimen may be used. The lack of experience with large transformers prevents the establishment of a standard test model. In the use of reduced-size specimens, adequate consideration shall be given to all the conditions and environments affecting the life of the simulated transformer. Each situation may involve a number of different arrangements to cover adequately the various combinations of conditions affecting the performance of the insulation system. It shall be the responsibility of each testing laboratory to select and use suitable models. Full and complete design information on the models shall be published at the time the test data is presented.

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[2]ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (http://www.astm.org/).

[3]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://www.standards.ieee.org/).

[4]NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://www.global.ihs.com/).

Whether the test specimens are actual transformers or models, consideration shall be given to the following items when designing and building the specimens:

a) The materials that are used for the various components of the specimen shall be representative of those that ultimately will be used in actual transformers. It is suggested that only insulating materials on which life data are available be used in system evaluations. Everything possible shall be done to assure that the individual components are uniform and representative of those used in actual service.
b) Insulation thickness and creepage distances shall be appropriate for the voltage class and industry or equipment standards or practices. The presence of partial discharge in an insulation system will have some effect on the system's life, and its presence in the test sample may prejudice the temperature aging results.
c) The arrangement of the different components, such as conductors, insulations, supporting members, spacers, shields, and ground, should duplicate electrically, thermally, and mechanically the conditions existing in the actual transformer.
d) The design and construction of the specimens shall be representative of the prevailing engineering practices and manufacturing procedures and processes.
e) Provisions shall be made for making electrical test on the various insulation components.
f) If self-heating is used, provisions shall be made for exciting and loading the specimen.

4. Test procedures

All test specimens shall be subjected to initial screening tests followed by repeated test cycles, consisting of the parts as given in order in Table 1. Where indicated, specific values for some of the test conditions will be found in Table 2, which provides varying degrees of severity depending on the application.

It is recognized that for some transformers there may be special requirements other than those represented in this standard, such as ability to withstand surge tests, direct-current polarizing voltages during moisture exposure, and so forth. For these cases, special exposure and tests should be formulated and added to the test cycle recommended herein.

It is also recognized that, depending on the test facilities available, the type of specimen employed, and other factors, slight variations in the methods of exposing the specimen may be necessary. It is all-important that, when any two different materials or insulation systems are compared, the test specimens of each shall be subjected to precisely the same exposure and other conditions of test. Unless otherwise specified, tests shall be carried out at normal room temperature and humidity (25 °C ± 5 °C, 50% relative humidity ± 10% relative humidity).

4.1 Initial screening tests

All test samples shall be subjected to dielectric screening tests prior to exposure to an elevated temperature on the first test cycle. The screening tests shall consist of the following steps and shall be conducted in the order given:

a) Initial dielectric proof test (see 4.6.1 for details)
b) Mechanical stress (see 4.3 for details)
c) Thermal shock (see 4.4 for details)
d) Moisture exposure (see 4.5 for details)
e) Dielectric proof test (see 4.6.2 for details)

Test specimens that fail the screening tests shall not be used.

Table 1—Test schedule

Purpose	Part	Test	Remarks	Reference section
Initial test	I	Dielectric proof test	Beginning of first cycle only	4.6.1
Basic cycle test	II III IV V VI	Temperature aging Mechanical stress Thermal shock (when specified) Moisture exposure (special atmosphere) Dielectric proof test	See Table 3 See Table 2 See Table 2 See Table 2	4.2 4.3 4.4 4.5 4.6.2
Continual testing	—	Repeat the basic tests cycle until failure occurs (Parts II–VI)	—	4.2

Table 2—Test conditions imposed on transformers for different applications

Test	Indoor	Outdoor[a]	Contamination atmosphere	Reference section
III Mechanical stress	15 m/s^2 for a period of 1 h	15 m/s^2 for a period of 1 h	15 m/s^2 for a period of 1 h	4.3
IV Additional thermal shock	None	–20 °C for 2 h	None	4.4
V Moisture exposure	48 h in 90–95% relative humidity at 5–10 °C above normal room temperature.	48 h in 100% relative humidity plus condensation at 5–10 °C	Duration and atmosphere as required for the specific application.	4.5
	After removal from humidity, the test specimens shall be held at normal room temperature and humidity for at least 20 min and not more than 30 min before applying electrical proof test.	After removal from humidity, the test specimens shall be held at normal room temperature and humidity for at least 20 min and not more than 30 min before applying electrical proof test.	Examples of contaminating atmosphere are salt or other spray, dust fog, immersion in salt of tap water, corrosive gas, or irradiation. Details should be noted carefully to permit duplication.	—
VI Dielectric proof test	—	—	—	4.6

[a]Meets or exceeds test requirements for indoor-applied transformers.

4.2 Temperature aging

The temperature-aging portion of the cycle shall be conducted at a minimum of three different temperatures, in accordance with the following recommended procedure. The aging temperatures and the duration of exposures at each temperature shall be selected so as to require 6–10 test cycles to reach the average time to end-of-life for a group of samples.

The highest aging temperature shall result in an average time to end-of-life of at least 100 h. The lowest aging temperature shall result in an average time to end-of-life of at least 5000 h. A 15–35 °C difference between aging temperatures is recommended. Table 3 will serve as a guide to selection of test temperatures.

Table 3—Suggested aging temperatures and exposure times per cycle

Exposure time per cycle (h)	Hottest-spot temperature (°C) or equivalent for systems expected to operate at:					
	105 °C	**130 °C**	**150 °C**	**185 °C**	**220 °C**	**250 °C**
168–672	120	145	165	200	235	265
48–336	135	160	180	220	255	285
24–72	150	175	195	240	275	305

A duration (period) of exposure is assigned to each selected aging temperature. It is suggested that an aging period of 24–72 h be used for the highest aging temperature, 48–336 h be used for intermediate aging temperatures, and 168–672 h be used for the lowest aging temperature. If less than one-half of the specimens reach end-of-life after completion of eight test cycles, the aging period shall be doubled. If one-third or more of the specimens reach end-of-life after completion of three test cycles, the aging period per cycle shall be halved.

Table 3 is intended to guide selection of aging temperatures and exposure times. The suggested aging temperatures and exposure times do not describe any actual insulation systems. The suggested aging temperatures and exposure times cannot be expected to result in the same end points for all insulation systems. The life-temperature relationship for a specific insulation system is relative and it must be compared to similar data for a system of known reliability and service life to be significant. Suggested aging temperatures in Table 3 are based on guidelines in IEEE Std 99-1980.

4.2.1 Recommended procedure

a) Temperature aging shall be done by exciting the transformers or test models at rated voltage and causing current to pass through the conductors until the desired test temperature is attained. When conservation of power and simplification of the test setup are important, the transformer may be loaded in a buck-boost or opposition arrangement.

b) The test temperature is that of the hottest spot in the windings. The relationship of the hottest-spot temperature to the average windings temperature, determined by change of resistance, or to the temperature of an embedded detector, shall be determined for the specimen under test. (It is recommended that a formula be derived relating hottest-spot temperature rise above average winding temperature to unit size, and so forth.)

c) During thermal aging, the movement of air at the surface of the specimen shall be substantially only the convection caused by the specimen itself and shall not constitute forced or restricted cooling. The ambient temperature shall be between 20 °C and 40 °C.[5] After the test temperature defined in procedure b) has been reached and made stable by the adjustment of current described in procedure a), further control of the test temperature may be obtained by either

    1) Controlling the current in the conductors to maintain the temperature of the hottest winding within ±2 °C as indicated by the change of resistance[6] method.

    2) Controlling the current in the conductors to maintain the temperature of a high-temperature location in or on the specimen within ±2 °C, as indicated by suitable temperature-sensing means.

    3) Controlling the ambient temperature within ±2 °C and the applied voltages within ±1%, while the loading means is fixed.

    Regardless of the method of temperature control used, the temperature of the hottest winding shall be determined by the change-of-resistance method or an embedded detector at the conclusion of the thermal aging portion of the test cycle.

d) The temperature aging shall be carried out at three or more different temperatures. It is suggested that a minimum of 10 specimens of the same type be tested at each temperature.

4.2.2 Alternate procedure for oven-aged nonenergized samples

a) Temperature aging shall be done by placing the samples in an accurately controlled oven with forced circulation at the desired temperature. The temperature throughout the oven shall be within ±2 °C of the specified exposure temperature.

b) The temperature aging shall be done at three or more different temperatures. From a statistical approach, it is suggested that a minimum of ten specimens of the same type be tested at each temperature.

4.3 Mechanical stress

After temperature aging (as described in 4.2), each transformer or test model shall be vibrated in simple harmonic motion to give the peak acceleration and the number of cycles duration shown in Table 2.

The transformers or test models shall be so mounted that the motion occurs parallel to the axis of the coils. This vibration test shall be made on samples at room temperature with normal humidity and without any applied voltage. The vibration frequency shall not exceed 60 Hz, and resonant frequencies of the specimen should be avoided.

4.4 Thermal shock

After temperature aging and mechanical stress (as described in 4.2 and 4.3), each transformer or test model shall be placed in a low-temperature chamber maintained within ±5 °C of the value and for the duration shown in Table 2. No voltage shall be supplied during this period.

[5] It is believed that transformers, to operate in ambient temperatures above 40 °C, should be tested in their normal operating ambients for a more accurate determination of life. More data is needed to verify this point.

[6] Permanent changes in wire resistance may be caused by aging at temperatures (above 250 °C for copper). Any such effect should be compensated for when using the change-of-resistance method of temperature measurement.

4.5 Moisture exposure

After temperature aging, mechanical stress, and thermal shock (as described in 4.2. 4.3, and 4.4), each transformer or test model shall be exposed for the duration and to the atmosphere specified in Table 2. No voltage shall be applied to the test specimens during this exposure.

Note that an atmosphere of 100% relative humidity with condensation is readily obtained by covering the floor of the test chamber with a shallow layer of water and using an immersion heater to heat the water to a temperature of from 5 °C to 10 °C above room temperature. It is preferable to adjust the voltage across the heater to maintain this temperature, rather than to attempt thermostatic control. The exterior walls of the moisture chamber should be thermally insulated. The roof of the chamber should be insulated and should be sloped so as to drain the condensed water to the back or sides of the cabinet and prevent drip on the samples. The interior of the cabinet should be constructed with overhanging lips so that moisture collecting around them will drain into the interior of the chamber. An atmosphere of approximately 93% relative humidity may be obtained by covering the bottom of the test chamber with a flat tray containing a saturated solution of ammonium dihydrogen phosphate ($NH_4H_2PO_4$) or sodium sulfate, with undissolved excess of the salt present, and by providing a fan for internal air circulation. Alternative methods of moisture may be found in ASTM E104-85(1991).

4.6 Dielectric proof test

A dielectric proof test consists of the application of voltage higher than rated voltage to a dielectric material for a specified time period. The purpose of the test is to determine the ability of the insulating materials and spacings to withstand an adequate, minimum voltage for a specified time without breakdown, flashover, or puncture.

Dielectric proof tests shall consist of applied voltage and induced voltage tests. The applied voltage test is intended to stress the insulation and spacings between windings and the insulation and spacings between windings and ground. The induced voltage test is intended to stress the insulation between conductors and the insulation between the layers of a winding.

4.6.1 Initial dielectric proof test

Initial dielectric proof tests shall consist of applied voltage and induced voltage tests under the conditions and at the voltages recommended by the applicable standard for the type of specialty or general-purpose transformer involved. Equipment for which no acceptable standard test is available may be tested according to the recommended procedures in 4.6.1.1 and 4.6.1.2.

4.6.1.1 Applied voltage test

a) The applied voltage test shall be made by applying between each winding separately, and all other windings and ground, a 60 Hz voltage from an external source. The winding(s) not under test shall be grounded during the test.
b) The duration of the applied voltage test shall be 1 min at the value specified in procedure c).
c) The rms test voltage shall be two times the rated rms voltage plus 1000 V. The rms test voltage shall be applied at a rate not to exceed 500 V/s.

4.6.1.2 Induced voltage test

a) The induced voltage test shall be made by applying across the terminals of any suitable winding a voltage that will stress the turn and layer insulation at a peak value of two times the rated peak voltage but will not stress interwinding, winding-to-core, or other insulation to voltages higher than

that specified in 4.6.1.1, procedure c). A frequency twice normal is usually required to avoid core saturation.

b) The induced voltage test shall be applied for 7200 cycles. The duration shall not exceed 60 s. Examples of equivalent tests are as follows:

Frequency (Hz)	Duration of test (s)
120	60
180	40
240	30
360	20
400	18
900	8

4.6.2 Dielectric proof test during basic test cycle

Dielectric proof testing is intended to disclose significant weaknesses that develop in the insulation system during the basic test cycle. The first proof test failure of any type in each test specimen establishes the end of life of the specimen. Dielectric proof tests shall be applied after completion of the minimum required exposure to humidity or other special environment. All dielectric proof tests shall be completed within 30 min after removal from humid or other special conditions.

a) For self-heated or oven-aged energized samples, the energizing of the samples at rated voltage during each temperature cycle is generally an adequate proof test.

b) Applied and induced voltage tests between turns, windings, and cores shall be used for oven-aged nonenergized samples. An induced voltage test at a test voltage equal to 65% of that used in the induced voltage test (as described in 4.6.1.2), and an applied voltage test at 1.5 times the rated rms voltage will provide adequate proof of dielectric integrity. The duration of the applied voltage shall be 1 min.

5. Interpretation of data

5.1 Criteria of failure

The criteria by which a test specimen is considered to have failed shall be fully defined prior to the start of the test. An adequate test shall be included in the test cycle to detect when a failure occurs. For example, fuse blowing can be used if current is selected as the failure criterion. The use of more than one criterion of failure will tend to make the interpretation of the test results more difficult. It is recommended that only one criterion be used.

The cause of all test-specimen failures should be determined. If it can be established that a failure was not within the insulation system under test, the data shall not be included in the analysis. If a failure is not within the insulation system and it can be repaired without disturbing the insulation system, the specimen should be put back on test. For example, an electric connection may open during the test. Since electric connections are usually not a part of the insulation system, the joint should be repaired and the specimen put back on test.

5.2 Method of determining average life

When all the test specimens have failed, the average life at each exposure point shall be calculated. It is recommended that the average life, in hours, be a geometric mean. The standard deviation of this life, in hours, and the 95% confidence limits of this life shall be calculated using the logarithms of the number of hours of life and by statistical methods. From these values, an indication of the accuracy of the average life values at each exposure temperature can be determined.

Methods for processing thermal aging data are given in IEEE Std 101-1987.

5.3 Extrapolation of data

The calculated regression line and the 95% confidence band can be used to determine the life and corresponding temperature for other than the test points. The extent to which data may reasonably be extrapolated is limited by the following requirements:

a) The calculated regression line plots as a straight line on the coordinate system specified in 5.5, item d).
b) The life to be expected at a lower temperature, which may be extrapolated from data taken at higher temperatures, must be considered to be anywhere between the upper and lower confidence limits existing at the desired temperature.

5.4 Application of results

As stated in the introduction of this standard, the results of the tests obtained by this procedure are for comparison purposes only. The results of a new system or system with modified materials are compared to the results of a well-known and field-service-proven system. Thus the validity of the acceptance of a new or modified system is by obtaining an equal or higher temperature index than the known system when the regression plot is extrapolated back to a reference hour.

It is recognized that it would be impractical to evaluate every transformer model and rating built by a manufacturer. For this reason, specialty transformers will have to be evaluated as classes and lines. Life test data could be applied to other transformer models and ratings that are

a) Constructed with the same materials and processes
b) Similar in configuration and construction type
c) Of the same ambient temperature class and have the same ultimate temperature

5.5 Report of results

Similar insulation systems may be used in different equipment and under varying exposure conditions. It is recommended for the sake of clarity that the test results be identified with the conditions of test and failure criteria, as well as the temperature classification and life expectancy.

A report of the results of the tests shall contain the following information:

a) Complete description of test sample (including insulation system)
b) Description of test cycle including dielectric tests, temperature aging, mechanical stress, thermal shock, and moisture exposure
c) Calculated regression equation with 95% confidence limits

d) A plot of the regression equation and confidence limits on coordinate paper with logarithm of life along the ordinate and reciprocal of absolute temperature along the abscissa. Graphs are normally scaled so that time, in hours, appears along the ordinate and temperature, in degrees celsius, appears along the abscissa of the coordinate paper.

Annex A

(informative)

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